Universität Zürich[UZH]

Institut für Epidemiologie,
Biostatistik und Prävention
Digital and Mobile Health Group

Final report on recruitment and results related to the SwissCovid app from the Zurich SARS-CoV-2 Cohort study (ZSAC)

Version 21.06.2021:

Contributors: Viktor von Wyl, Tala Ballouz, Dominik Menges, Paola Daniore

0. Introduction

The SwissCovid digital proximity tracing (DPT) app was released on 25 June 2020. In fulfillment of the mandate provided to Prof. Viktor von Wyl by the Federal Office of Public Health, this brief report aims to summarize existing research on SwissCovid. The report is structured into four sections. Section 1 provides an updated summary of existing research findings on SwissCovid. Section 2 discusses new results from the Zurich SARS-CoV-2 Cohort (ZSAC) study, which is partially funded by the FOPH mandate. Section 3 places official SwissCovid statistics into an international perspective and attempts to estimate population-level effectiveness along the lines of other recent research reports. Finally, in section 4 the report provides – from our perspective – some key lessons and conclusions.

1. The state of research about SwissCovid: what do we know after 12 months?

Because Switzerland had a comparatively early start in releasing its digital proximity tracing app, it has been relatively well researched. This is largely due to early and sustained collaborations with other ongoing, nationwide research projects on the SARS-CoV-2 pandemic, such as the Covid-19 Social Monitor (https://covid19.ctu.unibe.ch/) and Corona Immunitas (www.corona-immunitas.ch, which includes the Zurich SARS-CoV-2 Cohort ZSAC). These collaborations have contributed to the generation of important insights on the use and impact of SwissCovid on the population level.

In the beginning of the pandemic, a consortium of Swiss researchers developed a research agenda for a comprehensive evaluation of digital proximity tracing apps, including SwissCovid (https://smw.ch/article/doi/smw.2020.20324). The proposed research program centered around the three postulated main advantages of digital proximity tracing (DPT) apps over manual contact tracing (MCT): 1) DPT should be able to warn exposed contacts faster than MCT, 2) DPT should be able to reach exposed contacts who are not personally known to the infected index case, and 3) because notifications of exposed contacts are more automatized, DPT should still be able to function if MCT reaches capacity limits.

Regarding aim 1 (i.e., the demonstration of faster notification), ZSAC has published an analysis as a preprint (https://www.medrxiv.org/content/10.1101/2020.12.21.20248619v1, extensively described in our report to the FOPH in November 2020 and currently in peer review) that demonstrates that app-notified contacts with risk exposure in non-household settings entered quarantine, on average, 1 day earlier than contacts who did not receive an app notification. The exact reasons for this time difference are still being investigated, but the data suggests that 1 in 5 persons of the group with DPT app notifications received the notification before being reached by manual contact tracers. By contrast, notification of same-household exposed contacts was comparatively fast with and without DPT app notification, and no time difference was noted. Overall, this analysis was conducted in a welldocumented setting and was controlled for different confounders (such as factors associated with app usage). Despite, residual confounding cannot be fully excluded.

One limitation of the ZSAC study is that it only recruited participants who were eventually also identified as contacts by MCT. This limits the ability of ZSAC to investigate also the second aim of DPT, i.e. to reach and notify more persons. An analysis using the Covid-19 Social Monitor and published as a pre-print (https://dx.doi.org/10.2196/preprints.30004) provides further insights in this respect. The Social Monitor is conducted within an existing internet panel study (LINK-panel) and draws participants representatively with respect to age, gender and language region. The included surveys, conducted between December 2020 and April 2021, includes information from 2'403 participants (12'525 assessments of 2'403 individuals) on SwissCovid use, SwissCovid notifications, having done any SARS-CoV-2 tests in the past four weeks, positive SARS-CoV-2 tests in the past four weeks, and having been quarantined in the past four weeks. Overall, 46 (1.9%) respondents tested positive for SARS-CoV-2 in the follow-up period, 29 (1.2%) received an exposure notification (EN), and 130 (5.4%) were placed in quarantine. The analysis of actions taken upon EN, based on this sample, revealed that 22 out of 29 notified SwissCovid app users (75.9%, 95% confidence interval [CI]: 60.3-91.5%) took at least one mitigative action after receiving an EN. Furthermore, out of 20 EN-warned respondents who sought testing after an EN, 6 (30.0%, 95% CI: 11.9-54.3%) tested positive for SARS-CoV-2 following receipt of an EN, which is over three times more than SwissCovid app users who got tested without receipt of an EN (8.0%, 95% CI: 5.0-11.9%). While the estimate of 30% test positivity upon EN very likely is an overestimation, it can nevertheless be interpreted as a sign that persons who received an EN indeed had a substantial exposure risk.

Other studies have also looked into the third possible advantage of DPT, a better potential scalability in the face of rising SARS-CoV-2 case numbers. One study simulated the notification cascade using aggregated, publicly available and research data – an early analysis was already included in the report to the FOPH in November 2020 (https://jamanetwork.com/journals/jamanetworkopen/fullarticle/2779376). The primary intent of the simulation was to quantify the effect of SwissCovid notifications on pandemic mitigation in the Canton of Zurich. The study found that, for the month of September 2020, an equivalent of 5% of all persons in mandatory quarantine in Zurich received a recommendation for voluntary quarantine based on an app notification. Moreover, 30 persons tested positive for SARS-CoV-2 following an app notification. An extension of the analysis to October 2020 also revealed difficulties of the app notification cascade in adapting to the steeply rising case numbers in the second half of October 2020 and beyond.

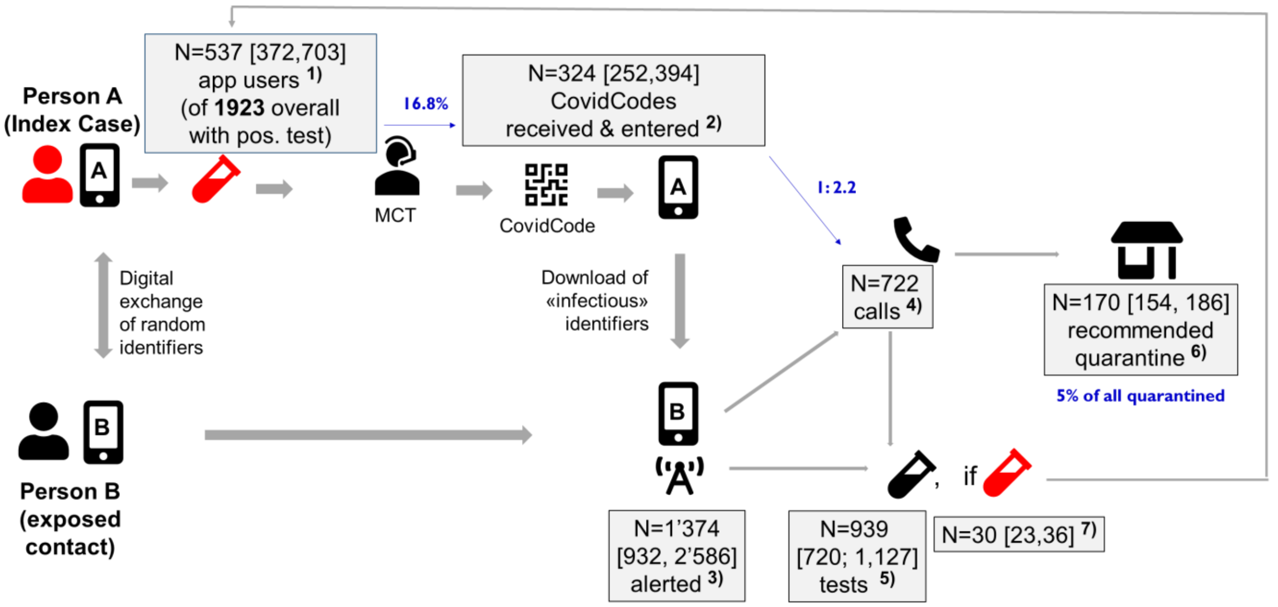


Figure 2: Simulation of notification cascade for the Canton of Zurich, September 2020. A description of the methodology can be found in https://jamanetwork.com/journals/jamanetworkopen/fullarticle/2779376

These findings showed that the SwissCovid DPT notification cascade did not scale as hoped with rising case numbers. This is expressed, for example, by the ratio of entered CovidCodes over the number of SARS-CoV-2 cases dropping nationwide from 16.3% in September 2020 to 12.4% in the second half of October 2020. Along similar lines, while 6 in 10 positive tested app users entered a CovidCode in September, this value was closer to 4 in 10 persons in October according to the same study. Similar trends were noticed for other performance indicators such as the number of infoline calls per entered CovidCode. On the positive side, several measures have been undertaken to mitigate the bottlenecks relating to the CovidCode generation process. In October 2020, the CovidCode generation process was separated from MCT and cases were able to personally request codes through text messages. Additionally, the infoline was scaled up to handle higher call volumes, and additional health service providers were able to generate and issue CovidCodes. As of December 2020, CovidCodes were generated and sent automatically after completion of an online form, which was implemented as the first step in MCT in the Canton of Zurich. Other delays were sometimes rooted in handling and turn-around times of SARS-CoV-2 PCR-tests. It seems that the broader availability of SARS-CoV-2 antigen rapid tests has also had a positive influence on the speed of the notification cascade, as evidenced by improvements in the time from symptom onset to CovidCode uploads in persons tested positive for SARS-CoV-2 (https://www.experimental.bfs.admin.ch/expstat/de/home/innovative-methoden/swisscovid-app-monitoring.assetdetail.14427231.html).

2. Additional results from the Zurich SARS-CoV-2 Cohort (ZSAC) Study

In most of the investigations on SwissCovid effectiveness, the ZSAC study played an important role. To our knowledge, it is one of very few studies worldwide to evaluate DPT apps in the context of a population identified by manual contact tracing as 1) being SARS-CoV-2 positive (index cases) or 2) at risk due to close contact with SARS-infected individuals (close contacts). In our report of November 2020, we have already extensively described the recruitment methods and study population enrolled until September 30, 2020. ZSAC completed recruitment in January 2021 and enrolled a total of 1'106 index cases and 395 close contacts. The number of recruited close contacts was lower than expected because the stark rise of SARS-CoV-2 incidence in October and November 2020 forced contact tracing to increasingly prioritize the management of index cases and focused less on exposed contacts.

One of the key strengths of ZSAC is the high level of data granularity, which offers an opportunity to reconstruct the SwissCovid notification cascade in great detail. The following analysis aims to study the sequence, i.e. temporality, and actions in the notification cascade within pairs of index cases and close contacts identified through MCT (case-contact pairs). In total, 286 close contacts (linked to 201 index cases) were identified. The baseline characteristics of the study population are displayed in table 1.

Table 1: Baseline characteristics of pairs of index cases and close contacts available for data analysis from the Zurich SARS-CoV-2 Cohort (ZSAC) study, based on manual contact tracing in the Canton of Zurich.

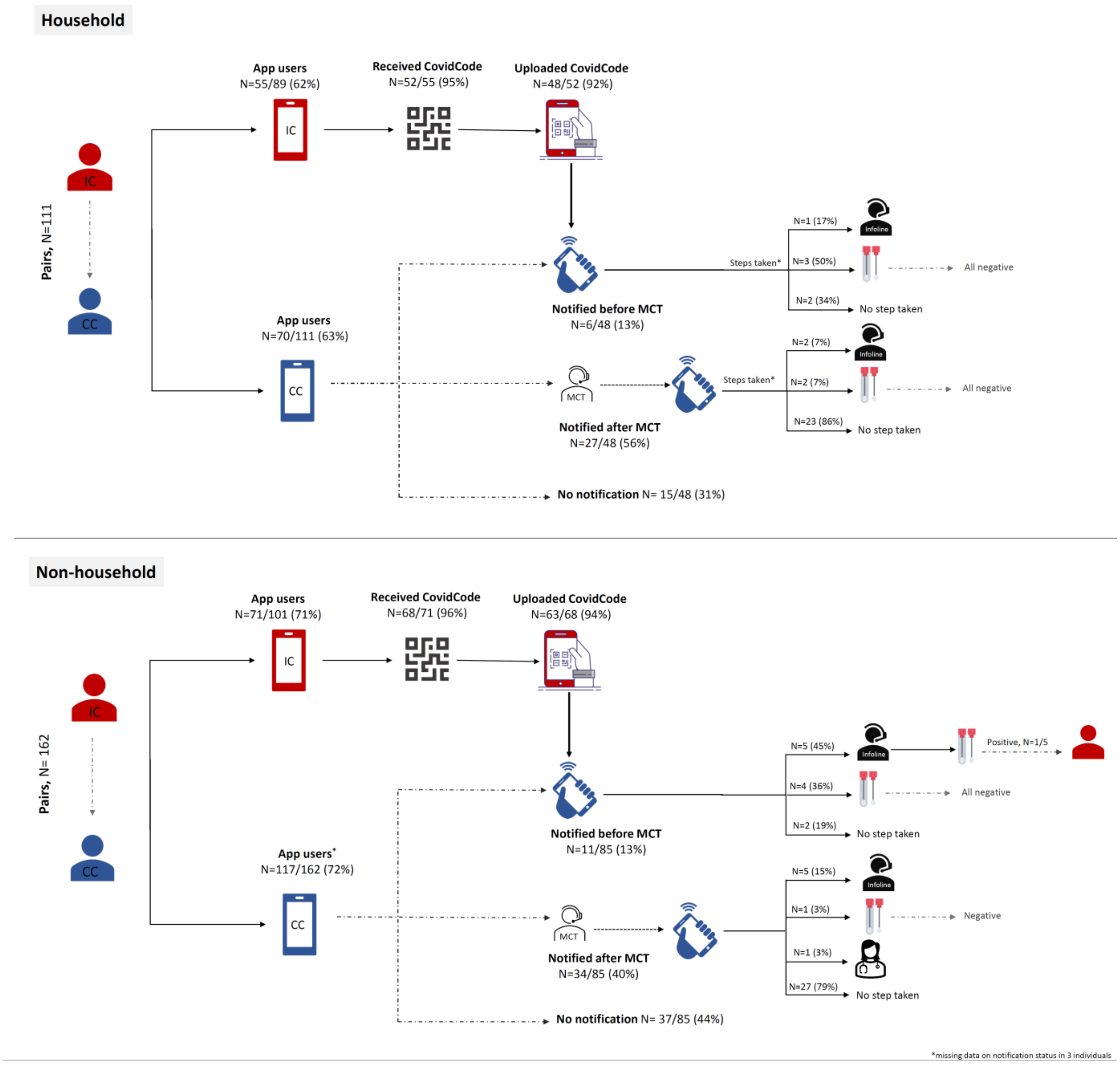
	Index Cases **N = 201**	**Close Contacts** **N = 286**
Age, years		
Median (25%–75%)	41 (30–57)	43 (30–57)
Sex		
Female	91/201 (45%)	147/286 (51%)
Male	110/201 (55%)	139/286 (49%)
Education		
Mandatory school	9/200 (4%)	12/285 (4%)
Vocational training/baccalaureate	82/200 (41%)	99/285 (35%)
Technical college or university studies	109/200 (55%)	174/285 (61%)
(Missing)	1	1
Employment status		
Employed	151/200 (76%)	205/285 (72%)
Unemployed	13/200 (6%)	54/285 (19%)
Student	36/200 (18%)	26/285 (9%)
(Missing)	1	1
Monthly household income		
<6'000 CHF	57/193 (30%)	85/252 (34%)
6'000-12'000 CHF	86/193 (45%)	105/252 (42%)
>12'000 CHF	50/193 (26%)	62/252 (25%)
(Missing)	8	34
Nationality		
Swiss	174/201 (87%)	256/286 (90%)
Non-Swiss	27/201 (13%)	30/286 (10%)
Chronic comorbidity		
At least one self-reported comorbid condition	45/198 (23%)	60/279 (22%)
No self-reported comorbid conditions	153/198 (77%)	219/279 (78%)
(Missing)	3	7
Known exposure setting		
Knows or has strong suspicion	96/201 (48%)	273/283 (96%)
No	105/201 (52%)	10/283 (4%)
(Missing)	0	3

	Index Cases N = 201	Close Contacts N = 286
Exposure setting (among those with known/suspected exposure)		
Household	15/95 (16%)	96/255 (38%)
Workplace	16/95 (17%)	33/255 (13%)
Private setting	25/95 (26%)	71/255 (28%)
Public space	21/95 (22%)	35/255 (14%)
Healthcare facility	1/95 (1%)	0
School/University	1/95 (1%)	5/255 (2%)
Other	16/95 (17%)	15/255 (6%)
(Missing)	1	18
SwissCovid app use		
App non-user	70/200 (35%)	88/284 (31%)
App user	130/200 (65%)	196/284 (69%)
(Missing)	1	2

Figure 2 reconstructs the notification cascade for same-household (n=111) and non-household (n=162) case-contact pairs. In same-household pairs (shown in the upper half of Figure 2), 48 index cases uploaded a CovidCode, thus triggering an EN. However, only 33 (69%) of the linked close contacts received an EN. Of the 33 notified contacts, 6 received the EN before having been reached by MCT, but only 4 of the 6 undertook preventive actions (3 sought testing and 1 called the infoline). Moreover, the vast majority of the 27 persons who received an EN after having been contacted by MCT did not undertake additional preventive measures as they were already in quarantine and often had already been tested for SARS-CoV-2.

The corresponding analysis of non-household case-contact pairs (n=162) is illustrated in the lower half of Figure 2. Of the 85 close contacts who could have potentially received an EN (because the index case uploaded the CovidCode), only 45 (53%) reported to have received a SwissCovid app warning. Furthermore, 11 of the 45 (24%) notified contacts received the warning before being reached by MCT. Nine of the 11 notified contacts undertook preventive actions, i.e., SARS-CoV-2 testing (5 also called the infoline), one of which tested positive for SARS-CoV-2. By contrast, of the 34 close contacts who received the EN after already being warned by MCT, the majority (n=27, 79%) did not undertake any additional steps. Therefore, approximately 1 in 4 (n=11, 24%) contacts with an EN received the warning before having been reached by MCT, of whom most (9 of 11 contacts) sought testing. Taken together, this data echoes findings that were already presented in an early preprint (https://www.medrxiv.org/content/10.1101/2020.12.21.20248619v1) from the ZSAC study: SwissCovid is likely to be more effective in the context of non-household exposures.

Figure 2: Reconstruction of the exposure notification cascade in same-household case-contact pairs (upper half) and non-household pairs (lower half).



Universität Zürich[UZH]

3. SwissCovid from an international perspective

3.1 Downloads and utilization of digital proximity tracing apps across different countries

As of 15 June 2021 (i.e., almost one year after the launch), the SwissCovid app has been downloaded more than 3.1 million times (36% of 8.6 million inhabitants) and currently has 1.7 million active users. Furthermore, 83'000 users have entered CovidCodes, and the infoline has been contacted 69'000 times either by telephone or through web forms ("Leitfaden SwissCovid") concerning the receipt of a SwissCovid app notification (https://www.experimental.bfs.admin.ch/expstat/de/home/innovative-methoden/swisscovid-app-monitoring.html, accessed 15 June 2021). By comparison, the German app has sent ENs for 478'000 positive test results and 747'500 calls were registered, in a population that is almost 10 times larger than Switzerland (83 million; 28.3 million app downloads, corresponding to 34% of the population; https://www.rki.de/DE/Content/InfAZ/N/Neuartiges_Coronavirus/WarnApp/Archiv_Kennzahlen/Kennzahlen_11062021.pdf). In the Netherlands, there were 4.96 million app downloads, corresponding to 28.7% of the total population (17.3 million), and 178'000 warnings have been issued (https://www.coronamelder.nl/media/Factsheet_Corona_latest.pdf). In the United Kingdom, 25.3 million app downloads have been registered in a population of 59.5 million inhabitants (42.5%) as per June 2021. When analyzing triggered app warnings upon testing positive for SARS-CoV-2 on a per capita basis, Switzerland had 965 EN triggers per 100'000 inhabitants, Germany had 900 EN triggers per 100'000 inhabitants, and the Netherlands had 1029 EN triggers per 100'000 inhabitants. However, the Netherlands had launched their app only in October 2020, whereas the Swiss and the German apps were launched in June 2020 (https://en.wikipedia.org/wiki/COVID-19_apps#List_of_countries_with_official_contact_tracing_apps). Information on per capita ENs are available for the UK in the publication by Wymant and colleagues (https://www.nature.com/articles/s41586-021-03606-z) for the September 2020 to December 2020 period. The authors reported 560'000 EN triggers (in a population of 59.4 million inhabitants), which is equivalent to 941 ENs per 100'000 inhabitants for that time period.

These limited international comparisons demonstrate that SwissCovid has reached an adoption rate and frequency of sending ENs upon positive SARS-CoV-2 test results that is comparable to those of other countries that are operating well-functioning apps according to the general perception.

3.2 International effectiveness studies

However, monitoring data are not completely informative with respect to the major question: What was the contribution of DPT apps on pandemic mitigation? Recently, studies have emerged that assessed the population-level effectiveness of DPT apps; most notably, a recent analysis from the United Kingdom was published in Nature (https://www.nature.com/articles/s41586-021-03606-z). This nationwide analysis investigated the impact of the NHS COVID-19 app between September and December 2020. The app was used by approximately 16.5 million users (28% of the total population), and 1.7 million ENs were sent, corresponding to 4.2 EN per index case. In their analysis, the researchers used the fact that app users entered their residential zip code to book SARS-CoV-2 tests through the app. This allowed them to conduct regionally stratified investigations into the relationship between app usage and SARS-CoV-2 incidence. Using mathematical models and statistical analyses that exploit regional heterogeneity, the authors concluded that the app prevented several hundreds of thousands of cases, ranging from 284’000 cases (central 95% range of sensitivity analyses: 108’000–450’000) to 594’000 (95% CI: 317’000–914’000) based on mathematical modelling and statistical comparison of matched neighbouring local authorities, respectively.

Along similar lines, the Robert Koch Institute recently stated in a press release that the Corona-Warn-App has been able to avert around 100’000 cases, however no methodological details were provided (https://www.heise.de/news/RKI-Schaetzung-Warn-App-hat-mehr-als-100-000-Infektionsketten-unterbrochen-6070747.html). The RKI study was also informed by app monitoring and incidence data, as well as post-notification surveys. This study assumes that through 4’000 persons triggering an EN on a given day during the third pandemic wave, between 20’000 and 40’000 app users were warned. Among these, 80% (16’000 to 32’000) were tested, leading to an additional daily detection of 1’000 to 2’000 infections (assuming a secondary attack rate of 6%).

3.3 An attempt to measure population-level effectiveness for Switzerland

The emergence of international effectiveness studies leads to the question as to whether similar calculations can be performed for Switzerland. Of note, in the time between the first and the second pandemic wave (July to October 2020), there were two studies that attempted to assess the population-wide impact of SwissCovid before the second wave (i.e. until October 2020) for Switzerland (https://smw.ch/article/doi/smw.2020.20457) and the Canton of Zurich (https://jamanetwork.com/journals/jamanetworkopen/fullarticle/2779376). Both studies indicate that some exposed contacts seek SARS-CoV-2 testing after receiving an EN and subsequently test positive.

However, there are some additional challenges when attempting population-effectiveness analyses for later pandemic phases (including the second wave) in Switzerland. Specifically, some of the key data assessed in the early analyses are currently no longer available. For persons with a positive SARS-CoV-2 test, the testing reason (including a SwissCovid notification) was collected as part of the mandatory (supplementary) reporting by treating physicians. This reporting was abandoned by November 2020 and has since never been resumed. Furthermore, testing reasons for persons who tested negative were never systematically reported. Overall, the lack of consistent data reporting severely impacted the possibilities to assess the population impact of SwissCovid during and after the second pandemic wave with high precision.

In the following section, we will take an attempt at a simplified population impact analysis using survey-based data, which has been continuously available throughout all pandemic waves. The calculations are intended to achieve a very rough projection of the population-wide impact of pandemic mitigation provided by the SwissCovid app and should, therefore, be interpreted with caution. Specifically, we aim to estimate the number of persons who tested positive after receiving an EN. We focus on the time period from 01 January 2021 to 30 April 2021. During this time, around 21’700 ENs were sent out, leading to the completion of 22’600 web forms (“Leitfaden SwissCovid”) or calls to the infoline (that is, measurable actions by notified contacts; *n.leitfaden* in formula below), and 1’600 quarantine recommendations. Overall, there were 206’000 positive SARS-CoV-2 tests recorded and average test positivity over the four months was 7.5% (although varying from almost 20% in January to 5% in April 2021; *%test.positivity* in formula below).

Two essential additional parameters need to be extracted from ongoing research studies, namely the proportion of all exposure-notified contacts who completed the web form or called the infoline (*%completer*; to calculate the number of individuals receiving an EN), as well as the percentage of exposure-notified persons who sought testing (*%tested*). Given these data, we can estimate the number of positive cases that were detected after receiving ENs as follows:

$$n.pos.cases.after.EN = \left[\frac{n.leitfaden}{\%completer}\right] * \%tested * \%test.positivity$$

The Corona Immunitas and the Social Monitor studies provide varying estimates for percentages of completers (50% and 25%, respectively) and the percentage of testers (around 60% in both studies). Therefore, by plugging in the %completer estimates from both studies we arrive at a range of **2'034 to 4'068 of SARS-CoV-2 positive tests detected after EN** from January to April 2021 in Switzerland. Compared to the overall number of positive tests during the same period, this amounts to a contribution of 1-2% of all identified positive cases (which is of similar magnitude as reported in the September/October analysis, https://jamanetwork.com/journals/jamanetworkopen/fullarticle/2779376).

An alternative calculation approach that can also be applied to the German and UK effectiveness analyses relies on a "multiplier" of the number of ENs sent per trigger. The UK study estimated the magnitude of the multiplying effect at 4.2 warnings per EN trigger, a Swiss study (https://jamanetwork.com/journals/jamanetworkopen/fullarticle/2779376) estimated this multiplier to be between 2.5 (all of Switzerland) and 4.2 (canton of Zurich) warnings per EN trigger, and the German results imply a multiplier ranging between 5 to 10. Given these multiplier estimates, the number of positively-tested persons after EN can be estimated as:

$$pos.cases.after.EN = [N.triggers * N.warnings.per.trigger] * \%tested * \%test.positivity$$

Using this alternative approach, we arrive at a range of **2'441 ("Swiss" multiplier) to 4'101 ("Zurich" multiplier) positive tests after EN**, which are almost identical to the estimates calculated with the first approach. By comparison, the German analysis claims that between 110'000 and 230'000 positive tests were detected after EN, amounting to between 3.8% and 7.9% of all 2.9 million positive tests overall between 01 June 2020 and 15 June 2021. Of note, the German study assumes a significantly higher amount of notified contacts per EN trigger than other countries (5 to 10, compared with around 4 notifications in the UK and in Switzerland). In addition, the UK study leads to an approximation of 141'000 positive tests after EN (7.5%) over 1'892'000 positive cases overall ([560'000 EN triggers * 4.2 warned contacts * 6% test positivity] / 1'892'000 positive cases), assuming that all notified contacts got tested.

Why do the Swiss numbers then seem substantially lower compared to its European counterparts, despite, e.g. similar estimates of test positivity or number of contacts informed per triggered EN as in the UK? If one looks at EN triggers per infected cases, substantial differences emerge. In the UK, 560'000 ENs were triggered by positively-tested persons, out of 1'892'000 positively-tested persons overall (29.6%) between September and December 2020. In Switzerland by comparison, 21'700 ENs were triggered out of 206'000 positive tested persons in total (10.5% between January and April 2021, resp. 11% between June 2020 and June 2021). In Germany, 474'500 ENs were triggered, out of 2.9 Mio positively-tested cases in total (16.4%) between June 2020 and June 2021. In other words, Switzerland had a lower proportion of positive tests leading to EN triggers.

EN triggers, in turn, are a function of the percentage of app users in the population and the percentage receiving and entering the upload authorization codes. As discussed elsewhere, the percentage of app downloads in comparison with the population size is highest in the UK (42.5%), followed by Germany

(34%) and Switzerland (36%). However, another statistic from the SwissCovid monitoring (https://www.experimental.bfs.admin.ch/expstat/de/home/innovative-methoden/swisscovid-app-monitoring.html) suggests that only 64% of all generated upload authorization codes were entered. That is, 1 in 3 codes were never used. For the UK and Germany, the respective percentages were 72% and 61%.

Therefore, the lower per capita and per SARS-CoV-2- case adjusted “effectiveness” (when defined as identifying secondary positive cases after EN) in Switzerland has different explanations. Effectiveness in the UK was likely higher due to a better app adoption and fewer lost ENs, whereas effectiveness estimates in Germany may be linked to the assumption of more than twice as many notified contacts per EN trigger (likely also reflecting less conservative Bluetooth signal thresholds for exposure determination).

3.4 Limitations of current effectiveness studies

By design, decentralized DPT (as implemented in the UK, in Germany, and in Switzerland) provides no individual-level information on the number of informed contacts or actions taken after receiving ENs. As revealed by our detailed analysis of the ZSAC study data and the Social Monitor, not all ENs directly lead to preventive actions. For example, the ZSAC analysis found that the potential speed advantage in alerting exposed contacts (relative to manual contact tracing) only became apparent in non-household settings. Moreover, numerous notified contacts reported not to have responded to the warning because they were already in quarantine or had been warned by other means. While the ZSAC analyses clearly describe temporality (e.g., relative to MCT) within different infection risk contexts (e.g., household, non-household), a direct inference of transmission prevention from ENs requires strong assumptions to be made. For example, the available effectiveness studies from the UK and Germany do not provide any insights as to whether the EN was truly the first and/or only warning source – even in persons who tested positive after receiving ENs. Although the UK study attempts to adjust for some of the factors, the effectiveness estimates, as well as those from the German study, likely represent an upper bound of effectiveness.

4. Conclusion and outlook

Despite current study limitations and knowledge gaps, the conclusion that DPT apps have had a measurable impact on pandemic transmission prevention appears robust. This notion is also underscored by our individual-level analyses of the notification cascade, which indicate a causality between EN and preventive actions exposed contacts for some (but not all) individuals with an EN. It is worthwhile to remember that the removal of infectious cases from transmission chains by isolation likely prevents further infections downstream. Through the effects estimated by different studies (i.e., SwissCovid leading to the identification of approx. 2’000 to 4’000 positively-tested persons after receiving an EN, faster quarantine of non-household contacts, and triggering quarantine recommendations in an additional 5% of exposed persons in the Canton of Zurich), the contribution of SwissCovid to pandemic mitigation was clearly relevant.

Other, much less explored, aspects of digital and manual contact tracing are the monetary costs and cost effectiveness of the different measures. Compared to DPT, MCT requires far more human involvement and has inferior scalability potential. That is, reducing or increasing the size of the MCT tracing workforce comes together with more friction (e.g. recruitment efforts, need for training, etc.). Therefore, it is plausible that the costs per identified positive SARS-CoV-2 case through EN may be lower than the costs of MCT. However, it needs to be re-emphasized that DPT is a complement to MCT – they are not in competition with each other but should ideally complement the other's respective weaknesses (e.g. better scalability and wider reach in DPT compared with MCT).

To summarize, there is now solid evidence that SwissCovid, overall, has successfully notified persons at risk and contributed to pandemic mitigation. However, the lackluster perception among the public and health care professionals serve as a strong reminder that effectiveness of digital proximity tracing is not just a matter of technological capabilities but also of appropriate education, application and implementation. Exaggerated expectations, lack of understanding of the interplay of SwissCovid with other actors and parts of the health care system, or unclear responsibilities are examples of some of the problems that have impacted the effectiveness of and undermined public trust of SwissCovid. Especially the processes for issuing CovidCodes and timely transmitting them to infected individuals were identified as an important bottleneck that may have impeded SwissCovid from achieving its full potential. On the positive side, throughout the pandemic, the responsible authorities have continuously adapted the technology and its processes to optimize the performance of the (technical and non-technical) SwissCovid system. However, future applications of the DPT technology should invest more resources into onboarding of relevant stakeholder groups (including the public and health system actors) and clearly define the role and niche within pandemic management. Furthermore, scientists and the public should re-adjust their expectations: **digital proximity tracing apps may not exert an impact in all settings and contexts, but we have good evidence that they work very well in some specific contexts.**

Universität Zürich[UZH]

Annex 1: Questions related to the SwissCovid app for index cases

	Gebrauch der SwissCovid App	
	Die SwissCovid App wird vom Bundesamt für Gesundheit herausgegeben, um Personen per Smartphone vor möglichen Ansteckungsrisiken zu warnen. Die App merkt sich, wenn ein Kontakt länger als 15 Minuten und näher als 1.5 Meter bestand. Wird bei einer Person mit der App das neue Coronavirus festgestellt, kann diese Person anonym andere App-Nutzerinnen/-Nutzer warnen, die sich während der Ansteckungsphase in ihrer Nähe aufgehalten haben.	
1.	Verwenden Sie die SwissCovid App?	• Ja, ständig • Ja, aber manchmal schalte ich Bluetooth aus, um die Funktion der SwissCovid App zu unterbrechen • Nein, ich habe die App wieder deinstalliert • Nein, aber ich plane Sie zu verwenden • Nein
2.	Wenn 1=Nein Weshalb verwenden Sie die SwissCovid App gegenwärtig nicht?	• Ich kenne die App nicht • Ich denke nicht, dass die App für mich nützlich ist • Ich kann die App nicht installieren (z.B. wegen technischer Probleme, weil ich kein Android oder iOS Smartphone habe) • Ich fürchte um meine Privatsphäre und den Datenschutz • Andere Gründe (bitte angeben)
3.	Wenn 1=Ja Hat die SwissCovid App schon mal eine Warnung ausgegeben, dass Sie mit einer mit dem Coronavirus infizierten Person in Kontakt waren?	• Ja, vermutlich wegen dem aktuellen Kontakt (d.h. in den letzten 7 Tagen) • Ja, zu einem früheren Zeitpunkt (d.h. vor mehr als 7 Tagen) • Ja, sowohl vermutlich wegen dem aktuellen Kontakt, wie auch schon einmal zu einem früheren Zeitpunkt • Nein, ich hatte bisher keine Warnung
4.	Wenn 3="Ja, aktuell" (Option 1 & 3) Haben Sie eine Warnung durch die SwissCovid App erhalten, <u>bevor</u> Sie vom kantonsärztlichen Dienst kontaktiert wurden?	• Ja • Nein
5.	Wenn 4="Ja" (Options 1-3) Welche Schritte haben Sie unternommen, nachdem Sie von der App gewarnt wurden?	• Ich habe die empfohlene Infoline SwissCovid angerufen • Ich habe andere Schritte unternommen, und zwar Folgende (bitte angeben) • Ich habe keine weiteren Schritte unternommen

Annex 2: Questions related to the SwissCovid app for closed contacts

Gebrauch der SwissCovid App

Die SwissCovid App wird vom Bundesamt für Gesundheit herausgegeben, um Personen per Smartphone vor möglichen Ansteckungsrisiken zu warnen. Die App merkt sich, wenn ein Kontakt länger als 15 Minuten und näher als 1.5 Meter bestand. Wird bei einer Person mit der App das neue Coronavirus festgestellt, kann diese Person anonym andere App-Nutzerinnen/-Nutzer warnen, die sich während der Ansteckungsphase in ihrer Nähe aufgehalten haben.

1. Verwenden Sie die SwissCovid App?

- Ja, ständig
- Ja, aber manchmal schalte ich Bluetooth aus, um die Funktion der SwissCovid App zu unterbrechen
- Nein, ich habe die App wieder deinstalliert
- Nein, aber ich plane Sie zu verwenden
- Nein

2. Wenn 1=Nein

Weshalb verwenden Sie die SwissCovid App gegenwärtig nicht?

- Ich kenne die App nicht
- Ich denke nicht, dass die App für mich nützlich ist
- Ich kann die App nicht installieren (z.B. wegen technischer Probleme, weil ich kein Android oder iOS Smartphone habe)
- Ich fürchte um meine Privatsphäre und den Datenschutz
- Andere Gründe (bitte angeben)

3. Wenn 1=Ja

Haben Sie einen CovidCode erhalten (Freigabecode, den Sie von den kantonalen Behörden aufgrund des positiven Coronavirus-Tests bekommen, um über die App andere Personen zu warnen)?

- Ja
- Nein

4. Wenn 3=Ja

Haben Sie den CovidCode in der SwissCovid App eingegeben, um die anonyme Benachrichtigung anderer App-Nutzer/-Nutzerinnen zu aktivieren?

- Ja
- Nein

5. Wenn 4=Nein

Können Sie den Grund angeben, warum Sie den CovidCode nicht aktiviert haben bzw. nicht aktivieren konnten?

Freitext

Annex 3: Existing studies of SwissCovid

Publications that used data from the Zurich SARS-CoV-2 Cohort (ZSAC) study

- A Data-Driven Simulation of the Exposure Notification Cascade for Digital Contact Tracing of SARS-CoV-2 in Zurich, Switzerland. D Menges, HE Aschmann, A Moser, CL Althaus, V Von Wyl. JAMA network open 4 (4), e218184-e218184

- Digital proximity tracing app notifications lead to faster quarantine in non-household contacts: results from the Zurich SARS-CoV-2 Cohort Study. T Ballouz, D Menges, HE Aschmann, A Domenghino, JS Fehr, MA Puhan, V von Wyl. medrxiv preprint: https://www.medrxiv.org/content/10.1101/2020.12.21.20248619v1

- Early evidence of effectiveness of digital contact tracing for SARS-CoV-2 in Switzerland. M Salathé, CL Althaus, N Anderegg, D Antonioli, T Ballouz, E Bugnion, S Čapkun, D Jackson, SL Kim, JR Larus, N Low, W Lueks, D Menges, C Moullet, M Payer, J Riou, T Stadler, C Troncoso, E Vayena, V von Wyl. Swiss Medical Weekly 150, w20457

Other publications on the effectiveness of digital proximity tracing apps under lead of V. von Wyl

- Challenges for nontechnical implementation of digital proximity tracing during the COVID-19 pandemic: media analysis of the SwissCovid app. V Von Wyl. JMIR mHealth and uHealth 9 (2), e25345

- Drivers of acceptance of COVID-19 proximity tracing apps in Switzerland: panel survey analysis. V von Wyl, M Höglinger, C Sieber, M Kaufmann, A Moser, M Serra-Burriel, MA Puhan. JMIR public health and surveillance 7 (1), e25701

- Towards a common performance and effectiveness terminology for digital proximity tracing applications. W Lueks, J Benzler, D Bogdanov, G Kirchner, R Lucas, R Oliveira, M Salathé, C Troncoso, V von Wyl. arXiv preprint arXiv:2012.12927

- A research agenda for digital proximity tracing apps. V Von Wyl, S Bonhoeffer, E Bugnion, MA Puhan, M Salathé, T Stadler, N Low. Swiss medical weekly 150, w20324

- Digital health and the COVID-19 epidemic: an assessment framework for apps from an epidemiological and legal perspective. KN Vokinger, V Nittas, CM Witt, SI Fabrikant, V von Wyl. Swiss Medical Weekly 150, w20282

- Use of Venn Diagrams to Evaluate Digital Contact Tracing: Results from a Panel Survey Analysis. P Daniore, V Nittas, A Moser, M Hoeglinger, V von Wyl. Preprint: https://dx.doi.org/10.2196/preprints.30004

Other articles / Outreach activities:

- SwissCovid zeigt Wirkung. V von Wyl. https://www.news.uzh.ch/de/articles/2021/Swisscovidapp.html (picked up by national media in all languages)

- Contact-tracing apps help reduce COVID infections, data suggest. D Lewis (Statements and work quoted by V von Wyl). https://www.nature.com/articles/d41586-021-00451-y

- Interviews for NZZ, Das Magazin, Heidi.news.

Presentation of SwissCovid results at high-level national and international symposia (also followed by Swiss press):

- Wehealth - The science of pandemics seminar meetings (https://www.youtube.com/watch?v=9zLJuDRh7js&list=PL02WmxHNLGkACVQ3eq_GFZtS-xoEXJAsP&index=5)

- The National Institute of Standards (NIST) https://www.nist.gov/news-events/events/2021/01/challenges-digital-proximity-detection-pandemics-privacy-accuracy-and

- The Graduate Institute Geneva: INCENTIVES TO INCREASE THE USE OF TRACING AND TESTING APPS: CARROTS OR STICKS? https://youtu.be/azW-EYaQ8Qw

- National Institutes of Health COVID-19 Exposure Notification Digital Tools Webinar: http://www.eebweb.arizona.edu/faculty/masel/wp-content/uploads/CovidUploads/CovidWebinar.pdf